VIII International Conference on Computational Plasticity
COMPLAS VIII
E. Oñate and D.R.J. Owen (Eds)
©CIMNE, Barcelona, 2005

DOES CRITICAL MODE I ENERGY RELEASE GOVERN COMPRESSIVE AXIAL SPLITTING OF BRITTLE MATERIALS? – ARGUMENTS FROM A COMBINED FRACTURE AND MICROMECHANICS APPROACH

Bernhard Pichler* **and Christian Hellmich***,†

*Institute for Mechanics of Materials and Structures (IMWS)
Vienna University of Technology (TU Wien)
Karlsplatz 13/202, A-1040 Vienna, Austria
†e-mail: Christian.Hellmich@tuwien.ac.at, web page: http://www.imws.tuwien.ac.at

Key words: Damage modeling, Micromechanics, Fracture Mechanics, Compressive axial splitting.

Summary. *In unconfined and confined uniaxial compression experiments on brittle materials – performed with proper lubrication of the interfaces between the load plates and the specimen – microcracks grow mainly in the direction of the governing principal compressive stress. This failure mechanisms is referred to as axial splitting. To model this behavior, we propose a micromechanics-based damage propagation law, by combining (i) the propagation law for a single penny-shaped crack embedded in an infinite matrix subjected to remote stress (by analogy to linear-elastic fracture mechanics) and (ii) stiffness estimates for RVEs of a material damaged by interacting microcracks (based on continuum micromechanics). It will be shown that this combined fracture-micromechanics damage model accounts for (i) tensile strain softening, (ii) compressive axial splitting, (iii) a realistic ratio between the uniaxial tensile strength and the uniaxial compressive strength, and (iv) the transition from axial splitting to faulting in confined uniaxial compression tests.*

1 INTRODUCTION: FAILURE MECHANISMS OF BRITTLE MATERIALS IN UNCONFINED UNIAXIAL COMPRESSION EXPERIMENTS

Laboratory experiments are useful to study the failure mechanisms of brittle materials. However, compression experiments performed with insufficient lubrication of the interfaces between the load plates and the specimen yield a misleading picture of the mechanisms of brittle failure in compression. In such tests, namely, friction at the aforementioned interfaces cause spatially non-homogeneous confining stresses within the specimen. Hence, the stress state within the testing sample is neither homogeneous nor uniaxial.

In unconfined uniaxial compression experiments on brittle materials – performed with proper lubrication of the interfaces between the load plates and the specimen – cracks nucleate at pre-existing material or geometric discontinuities such as grain boundary cavities, the interface between dissimilar materials, the intersection of slip bands with an adjacent grain [4], circular cavities, pores, and the immediate vicinity of soft inclusions [10]. These cracks are visible and, hence, open [10]; and they propagate in the direction of axial loading, through a predominantly mode I cracking mechanism, i. e. the relative displacement of the crack surfaces is perpendicular to the crack growth direction [10]. In the post-peak regime of such a test, crack propagation is accompanied by strain softening [9], whereby the number of cracks developing within a certain volume is rather large, such that the calculation of averages (e. g. of strains) is reasonable [9]. Accordingly [11, 12, 8, 3], one may treat this problem in the framework of continuum micromechanics of damaged materials. At the end of a uniaxial compression test on a brittle specimens, the sample splits up into many slender "columns", and final failure takes place due to bending, buckling and sliding of these columns [10].

2 MODELING OF AXIAL SPLITTING BY COMBINING FRACTURE AND MICROMECHANICS

To model the behavior described in the previous section, we propose a micromechanics-based damage propagation law by combining (i) the propagation law for a single penny-shaped crack embedded in an infinite matrix subjected to remote stress (by analogy to linear-elastic fracture mechanics) and (ii) stiffness estimates for representative volume elements of a material damaged by interacting, open microcracks (based on continuum micromechanics) [13, 1, 5, 2]. Thereby cracks are introduced as a morphological unit of the materials (rather than considering "smeared" effects of cracks), and only physically well-defined material parameters are introduced: the elastic constants and the critical mode I energy release rate of the brittle material, geometric properties of the penny-shaped microcracks and their number per unit volume.

3 PERFORMANCE OF THE PROPOSED DAMAGE MODEL

The proposed damage model allows for calculating the driving forces for axial splitting under unconfined uniaxial compression and under the more general case of confined uniaxial compression. The model accounts for several characteristic properties of brittle materials, such as, e. g., (i) compressive axial splitting, (ii) tensile strain softening [6], (iii) a realistic ratio between the uniaxial tensile strength and the uniaxial compressive strength, and (iv) the transition from axial splitting to faulting in confined uniaxial compression tests [7].

Because the combined fracture-micromechanics damage model so far gave satisfactory results [6, 7], one may well expect that the described approach can significantly enhance the insight into cracking of brittle materials and pave the way towards more realistic constitutive modeling of such materials subjected to mechanical loads.

REFERENCES

[1] V. Deudeé, L. Dormieux, D. Kondo, and S. Maghous. Micromechanical approach to nonlinear poroelasticity: application to cracked rock. *Journal of Engineering Mechanics (ASCE)*, 128(8):848–855, 2002.

[2] L. Dormieux and Kondo D. *Poroelasticity and damage theory for saturated cracked media*, chapter of Ref. [3]. 2005.

[3] L. Dormieux and F.-J. Ulm (editors). *Applied micromechanics of porous media.* CISM Course and Lecture Notes. Springer Wien New York, 2005. In print.

[4] S. Nemat-Nasser. Mechanics of materials and structural theories – mechanics of brittle failure in compression. *Computers & Structures*, 20(1–3):235–237, 1985.

[5] V. Pensée, D. Kondo, and L. Dormieux. Micromechanical analysis of anisotropic damage in brittle materials. *Journal of Engineering Mechanics (ASCE)*, 128(8):889–897, 2002.

[6] B. Pichler, Ch. Hellmich, and H.A. Mang. Does propagation of interacting microcracks cause tensile strain-softening of brittle materials. *International Journal of Fracture*, 2005. Submitted for publication in February 2005.

[7] B. Pichler, Ch. Hellmich, and H.A. Mang. Is confining-pressure dependent axial splitting of brittle materials governed by mode i energy release of interacting open microcracks? – arguments by a combined fracture-micromechanics theory. *International Journal for Numerical and Analytical Methods in Geomechanics*, 2005. To be submitted for publication in June 2005.

[8] J. Salençon. *Handbook of Continuum Mechanics.* Springer Berlin Heidelberg, 2001.

[9] J. Vardoulakis, J.F. Labuz, E. Papamichos, and J. Tronvoll. Continuum fracture mechanics of uniaxial compression on brittle materials. *International Journal of Solids and Structures*, 35(31–32):4021–4353, 1998.

[10] E.Z. Wang and N.G. Shrive. Brittle fracture in compression: mechanisms, models, criteria. *Engineering Fracture Mechanics*, 52(6):1107–1126, 1995.

[11] A. Zaoui. *Matériaux hétérogènes et composites [Heterogeneous materials and composites].* Lecture Notes. École Polytechnique, Paris, France, 1997. In French.

[12] A. Zaoui. Structural morphology and constitutive behavior of microheterogeneous materials. In P. Suquet, editor, *Continuum Micromechanics*, pages 291–347, Wien, 1997. Springer.

[13] A. Zaoui. Continuum micromechanics: Survey. *Journal of Engineering Mechanics, ASCE*, 128:808–816, 2002.